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GROUNDWATER FLOW PATTERN IN NORDIC WEST ARM TAILINGS AREA

T.P. LIM, N.K. DAVE AND A. VIVYURKA

ELLIOT LAKE LABORATORY

FEBRUARY 1983

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38pp

MINERALS RESEARCH PROGRAM
MINING RESEARCH LABORATORIES
DIVISION REPORT MRP/MRL 83-34 (TR)

GROUNDWATER FLOW PATTERN IN NORDIC WEST ARM TAILINGS AREA

by

T.P. Lim*, N.K. Dave** and A.J. Vivyurka†

ABSTRACT

Piezometers were installed in 1980 in the Nordic West Arm tailings area to monitor the groundwater flow pattern within the tailings pile.

Contour maps of the pressure head and flow patterns were constructed from the data obtained during fall 1980, summer 1981 and spring 1982. The results indicated that the groundwater in the tailings pile flowed in general away from the centre of the tailings area in the east and west direction.

The eastern half of the tailings area showed an erratic flow pattern giving a non-uniform gradient distribution caused by a multi-directional inflow. The groundwater outflow from this area, therefore, could not be computed with any accuracy.

The western half of the tailings area showed a more homogeneous unidirectional flow pattern than the eastern half. Geologically, it is situated in a narrow glaciated valley shaped like a channel, thus directing the groundwater flow westerly towards Westner Lake. Compared to the eastern half, the western half of the tailings area provided a more suitable site for calculating, with a reasonable accuracy, the groundwater outflow from the tailings area to the surrounding environment.

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* Physical Scientist, ** Research Scientist, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario, Canada.
† Sr. Environmental Engineer, Rio Algom Limited, Elliot Lake, Ontario, Canada.

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INTRODUCTION

A groundwater monitoring programme on the Nordic West Arm tailings area has been carried out since 1976. It was expanded in 1980 in order to determine the groundwater flow pattern and the water quality within the tailings pile so that an assessment of its impact on the surrounding environment could be undertaken. The groundwater flow net pattern is required for selecting a suitable location on the Nordic West Arm tailings area for:

1. Calculating the groundwater flow of seepage effluents from the tailings area into the surrounding environment;
2. Developing an environmental impact model of contaminants migrating from the tailings area;
3. Understanding the mechanisms and interactions between various solid and liquid phase chemical and radioisotope constituents, as they migrate along the pathway into the surrounding environment.

The selected site and groundwater flow pattern should meet the following criteria:

1. A stable and consistent flow pattern with a reasonable unidirectional flow and uniform gradient;
2. A single source of seepage (point of origin);
3. A known controlled destination; and
4. A known or measurable cross-sectional area through which the seepage effluent passes.

The Nordic West Arm study site is located immediately west of the Nordic Main tailings impoundment as shown in Fig. 1. The tailings in the Nordic West Arm impoundment originated from the early operation of the Nordic mine uranium mill and was filled to its capacity by 1960.

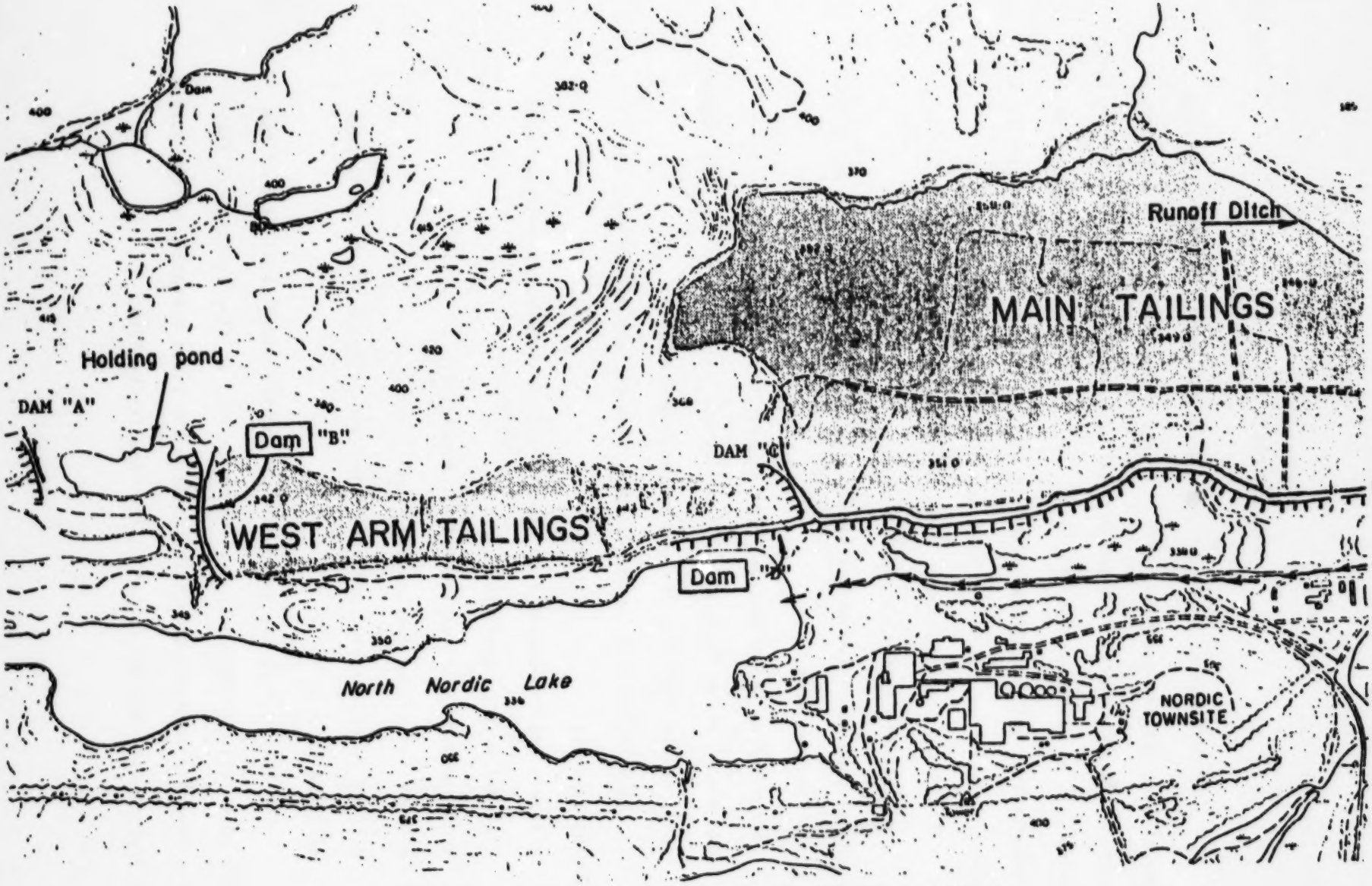

Fig. 1 - General site setting Nordic West Arm tailings (after Morrison and Beatty, 1980).

Details of the tailings and mine area geology, mining, milling and surrounding area geochemistry were described by Blair et al. (1). The tailings were deposited in the Nordic West Arm basin impounded by a dam 'B' (Fig. 1) on the western end of the valley. A second dam 'C' on the eastern end of the Nordic West Arm was constructed later to complete a larger tailings impoundment called the Nordic Mine tailings.

Surface water outlets are located at dam 'B' and 'C' in the form of man-made drainage ditches constructed across the dams. The east-end drainage ditch outflows towards an effluent treatment plant. Flow is intermittent and occurs after precipitation events and the spring recharge. Trickle flow occurs in the summer. The west-end drainage ditch, flowing into a holding pond, is above the water table during summer months and there is no surface water flow except during spring recharge and after precipitation events.

A preliminary hydrological budget of the area was conducted by Morrison and Beatty (2). In this present investigation, detailed groundwater hydrology of the Nordic West Arm was investigated over a period of three years. Three sets of seasonal data obtained during fall 1980, summer 1981 and spring 1982 are reported here.

METHOD OF INVESTIGATION AND PIEZOMETER INSTALLATION

For the tailings area hydrogeochemical investigations, piezometers, piezometer nests, and multilevel bundle piezometers were installed in the Nordic West Arm tailings pile and in the underlying unconsolidated glaciated deposit at locations as shown in Fig. 2 (3). The piezometers' tips are a modified casagrande drive point as described by Blair et al. (1) and shown in Fig. 3. The piezometers were constructed entirely of plastic material (PVC, nylon or polypropylene) to avoid corrosion in the acidic environment of the tailings.

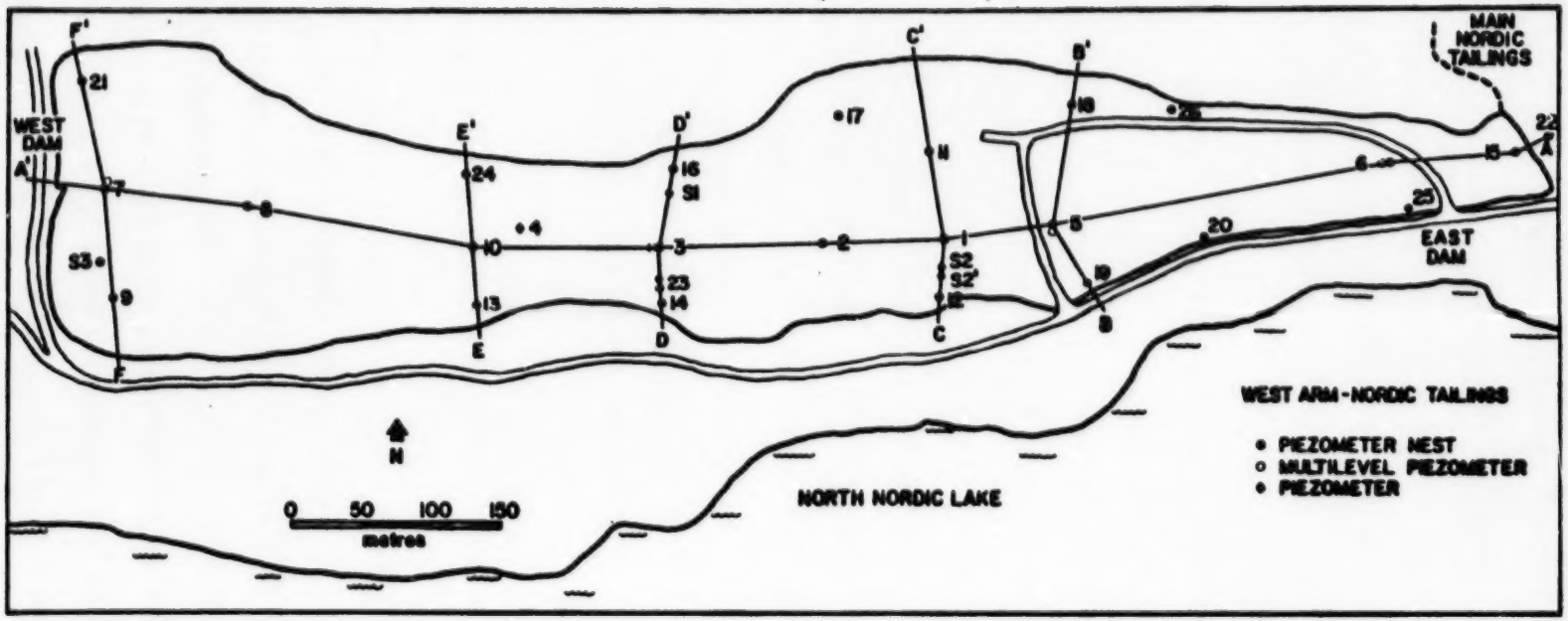

Fig. 2 - Location of piezometer installations and cross-sections in the West Arm - Nordic Tailings (after R. Blackport)

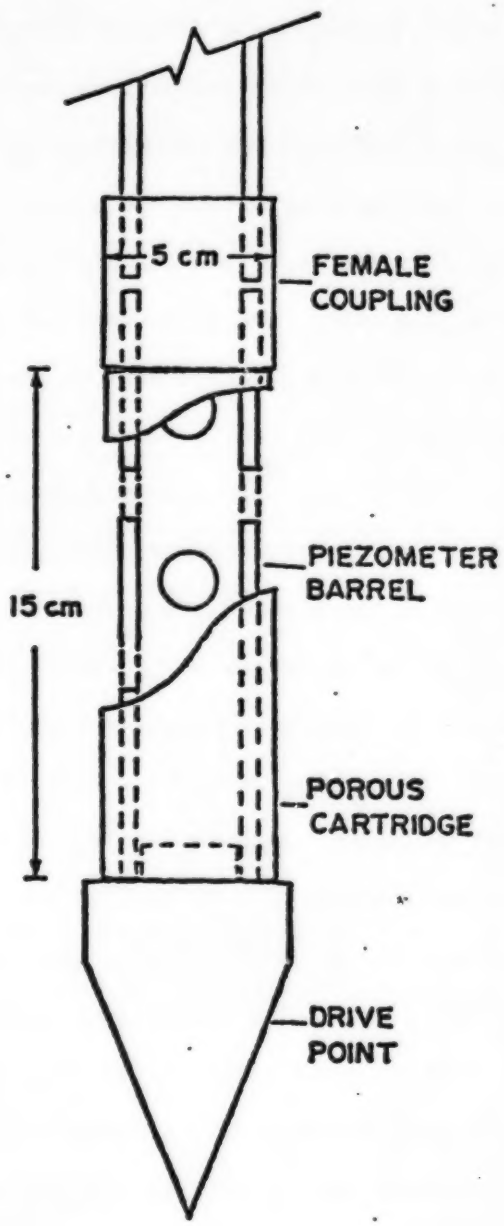

Fig. 3 - Design of piezometer tips used in tailings (Blair et al. 1980).

Figure 4 shows the installation sequence of piezometers. A CME 55 hollow stem auger drill, mounted on a tracked vehicle, was used for installation. A hole was drilled to a depth approximately one metre above the final elevation of the piezometer point (Fig. 4A). A retractable centre rod plug was used to prevent the flow of tailings slurry into the auger. At the desired depth, the plug was removed from the auger and the piezometer assembly was inserted into the hollow stem (Fig. 4B). The piezometer was then pushed down for the remaining metre using a gasoline powered percussion drill similar to the Atlas Copco - "Cobra" drill (Fig. 4B-C). A steel mandrel adapter provided the rigidity for driving the plastic pipe. During the advance, the tailings below the water table liquified around the piezometer pipe and settled back tightly afterwards around the pipe. This provided minimal disturbance around the piezometer point in the formation at the specified depth. The hollow stem auger was then removed by turning it counter-clockwise while pulling it upwards. This helped backfill the tailings around the pipe (Fig. 4D). For piezometer nests, between three to seven piezometers were installed at one site.

The same technique was used to install piezometers and multilevel bundle mini-piezometers in the unconsolidated glacioflucial sand underlying the layer of black peaty material immediately beneath the tailings. Multilevel bundle piezometers were only installed in the unconsolidated formation where a horizontal hydraulic gradient existed. A bentonite seal was placed in the drill hole around the piezometer pipe to isolate the peat layer and the glaciofluvial sand beneath the tailings. Drilling mud was not used during piezometer installations so as to avoid cross contamination and achieve minimal disturbance around the drill hole.

All piezometers were cleaned after installation and prior to each measurement by pumping with either a battery operated peristaltic pump or a hand operated "Guzzler" vacuum pump. Measurements of pH, electrical conduct-

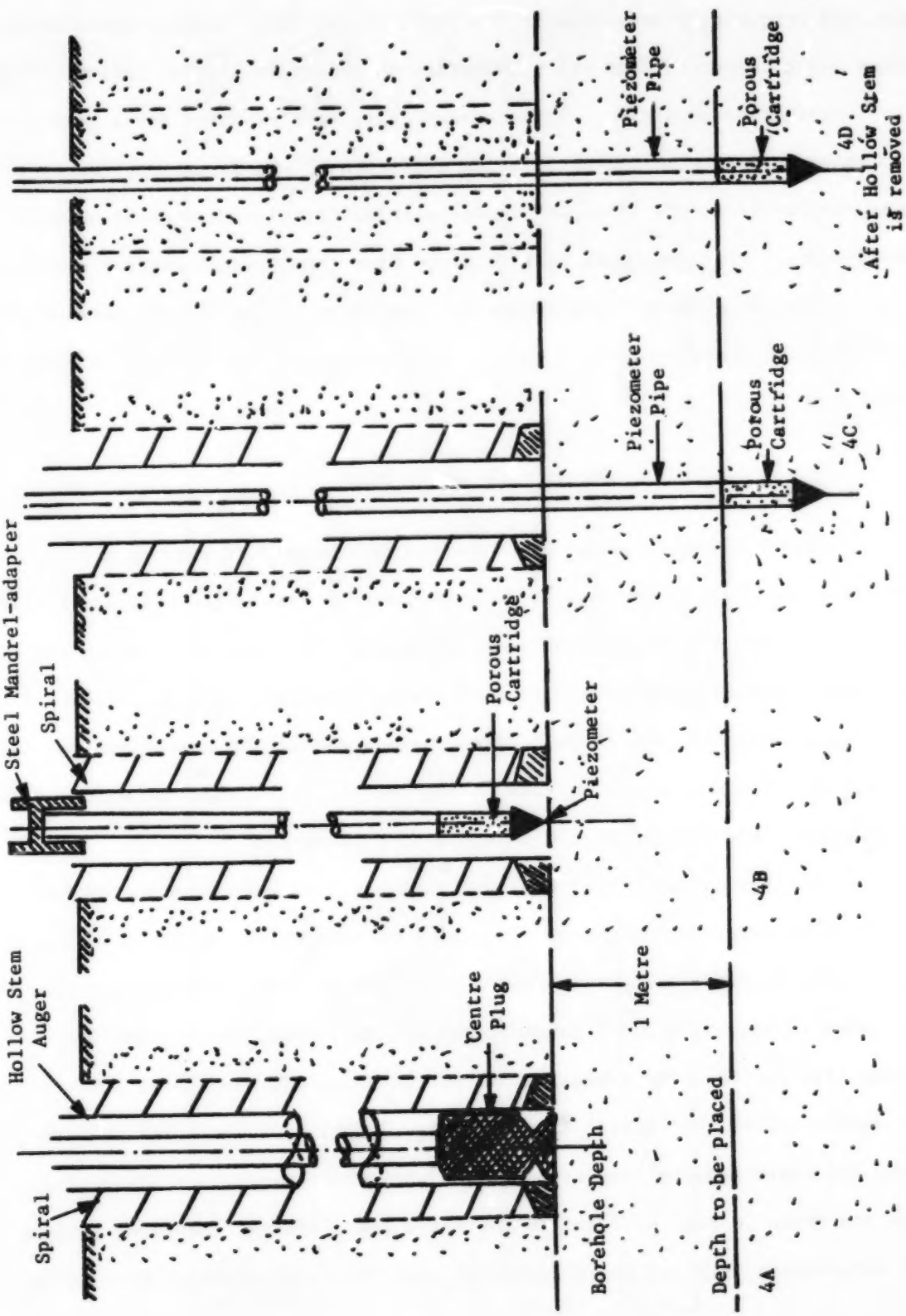

Fig. 4 - Piezometer installation sequence.

ance and temperature were done in the field on the water samples immediately after being recovered from the piezometers to obtain an initial indication of the installation condition. These measurements were repeated for a period of two weeks to determine the equilibrium condition of the formation. Water level measurements were then taken and recorded at equilibrium conditions using a water level probe. Pressure heads were obtained from the measured water elevations.

The location of each piezometer, as shown in Fig. 2, was surveyed in 1980 after installation and the elevation recorded with respect to a fixed bench mark.

RESULTS AND DISCUSSION

Water elevation data were recorded for three different seasons to determine seasonal variability of flow patterns in the Nordic West Arm tailings area. The first set of data was gathered in the fall of 1980. During the measurement some intermittent rain events were observed. The second set of data was collected in summer 1981 after three weeks of dry period and the third one was recorded during spring thaw at the end of April 1982. No winter data could be obtained because of the freezing of piezometers.

Pressure head contour maps and flow patterns were constructed from the recorded data for various tailings area cross-sections as shown in Fig. 2. The horizontal cross-sections at 342 m above the main sea land (MSL) elevation are shown in Fig. 5, 6 and 7 respectively for fall 1980, summer 1981 and spring 1982 periods. The elevation 342 metres above MSL was chosen arbitrarily for demonstrating the lateral flow patterns, location of the pressure head mound and their seasonal variations. The east-west vertical cross-sectional maps are shown in Fig. 8, 9 and 10 for the three different recording periods. The north-south vertical cross-sectional maps for cross-sections B'-B, C'-C,

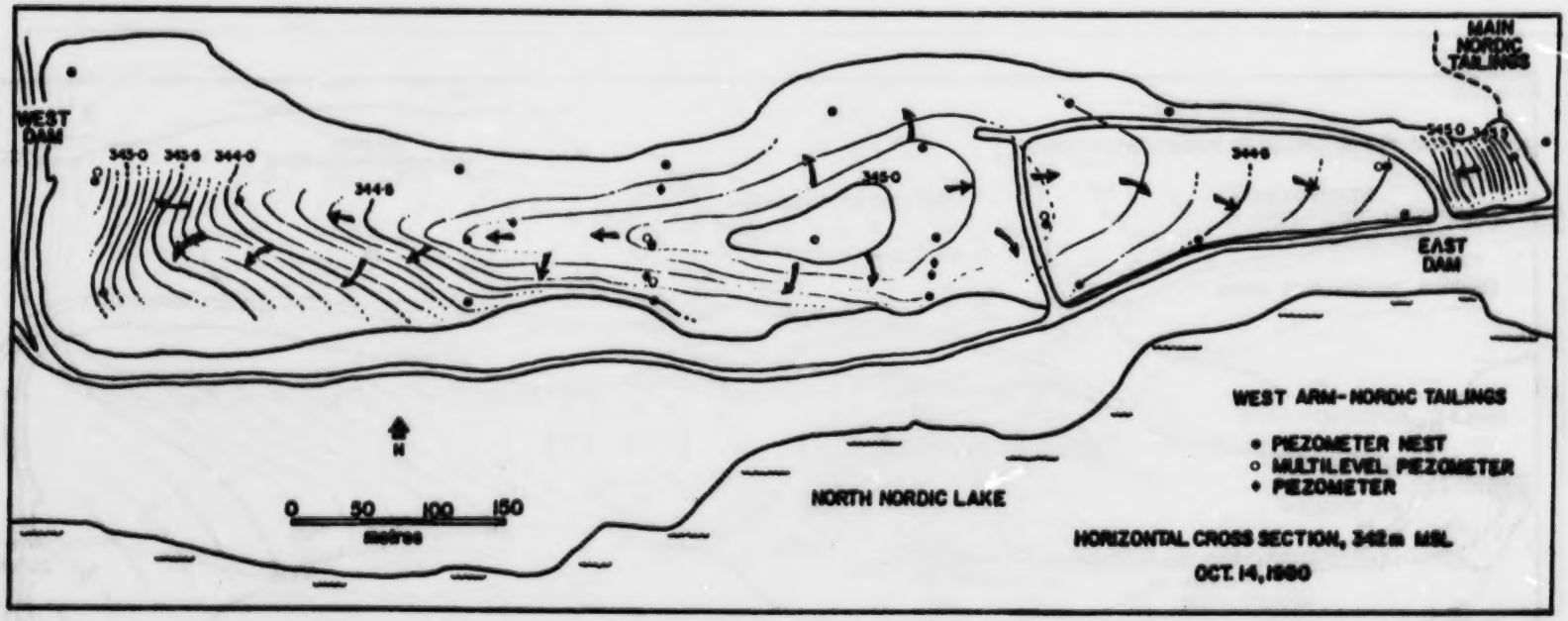

Fig. 5 - Horizontal cross-section, pressure contours & flow pattern in the Nordic West Arm tailings at 342 m (MSL) elevation, Fall 1980.

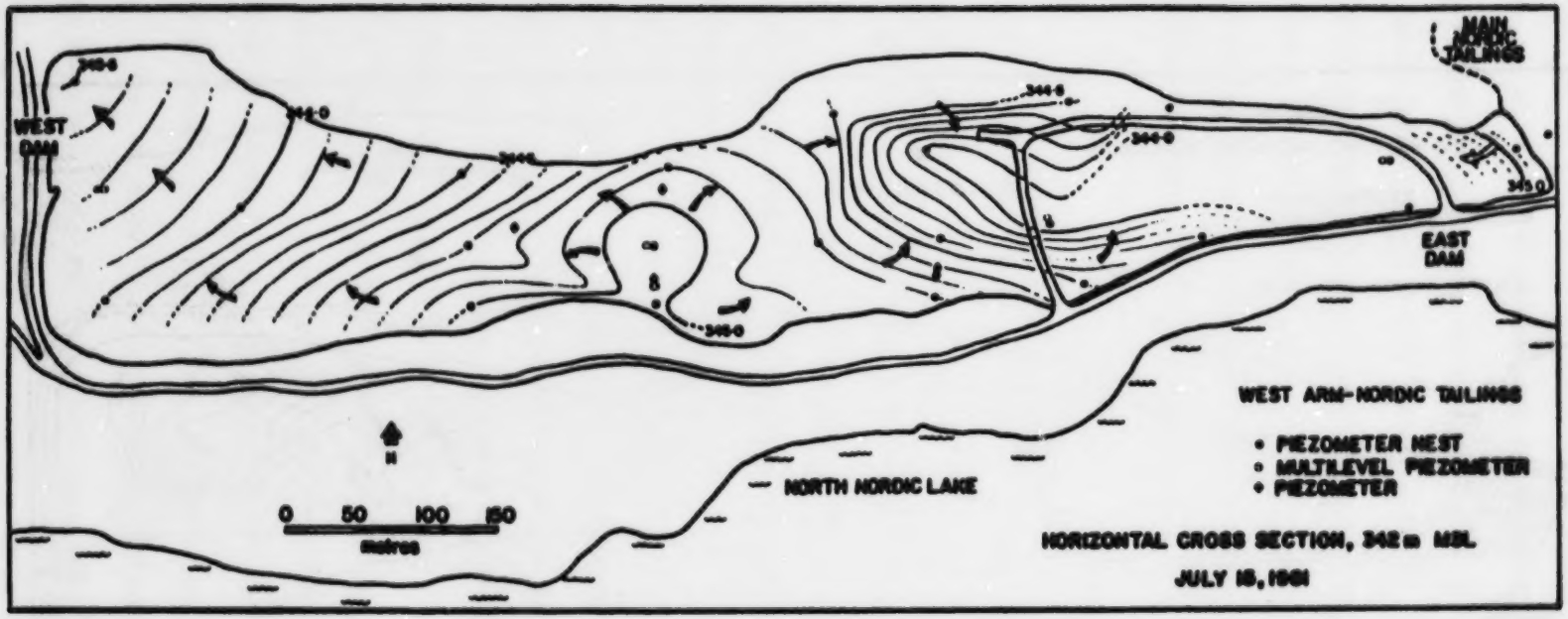

Fig. 6 - Horizontal cross-section, pressure contours and flow pattern in the Nordic West Arm tailings at 342 m (MSL) elevation, Summer 1981.

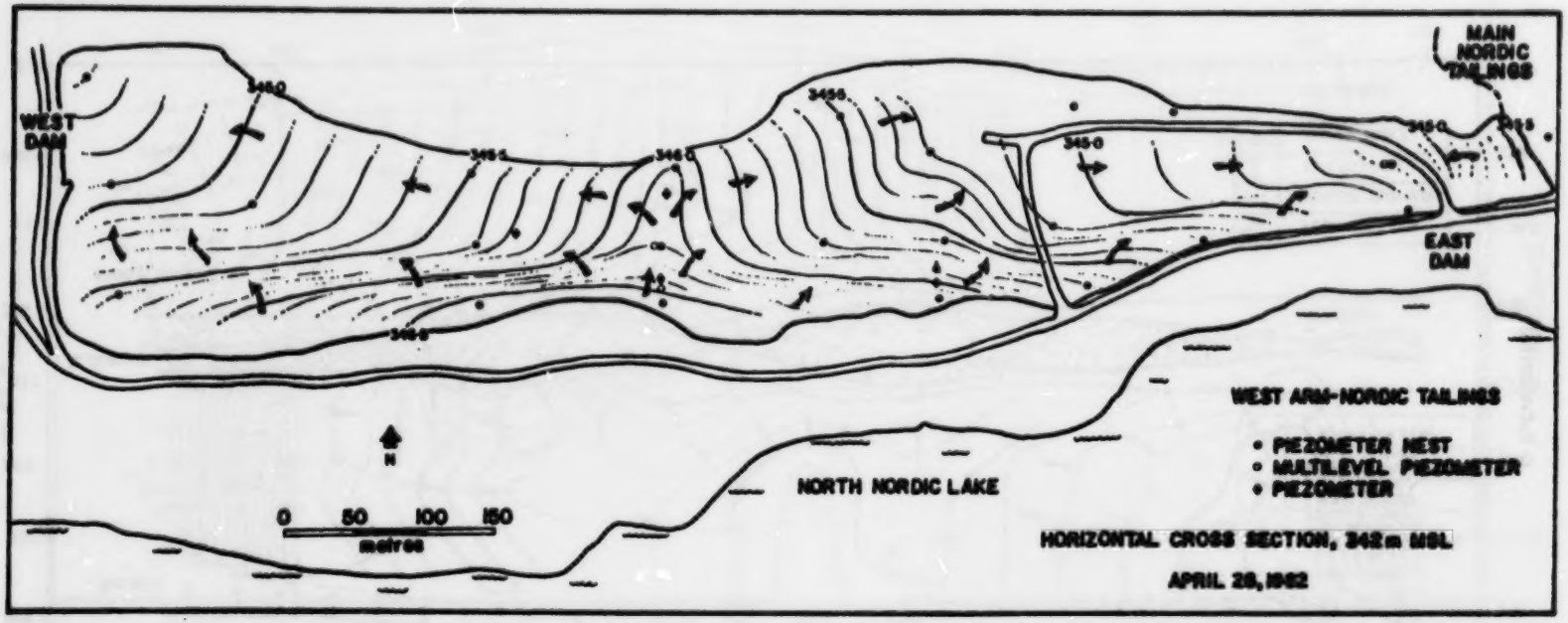

Fig. 7 - Horizontal cross-section, pressure contours and flow pattern in the Nordic West Arm tailings at 342 m (MSL) elevation, Spring 1982.

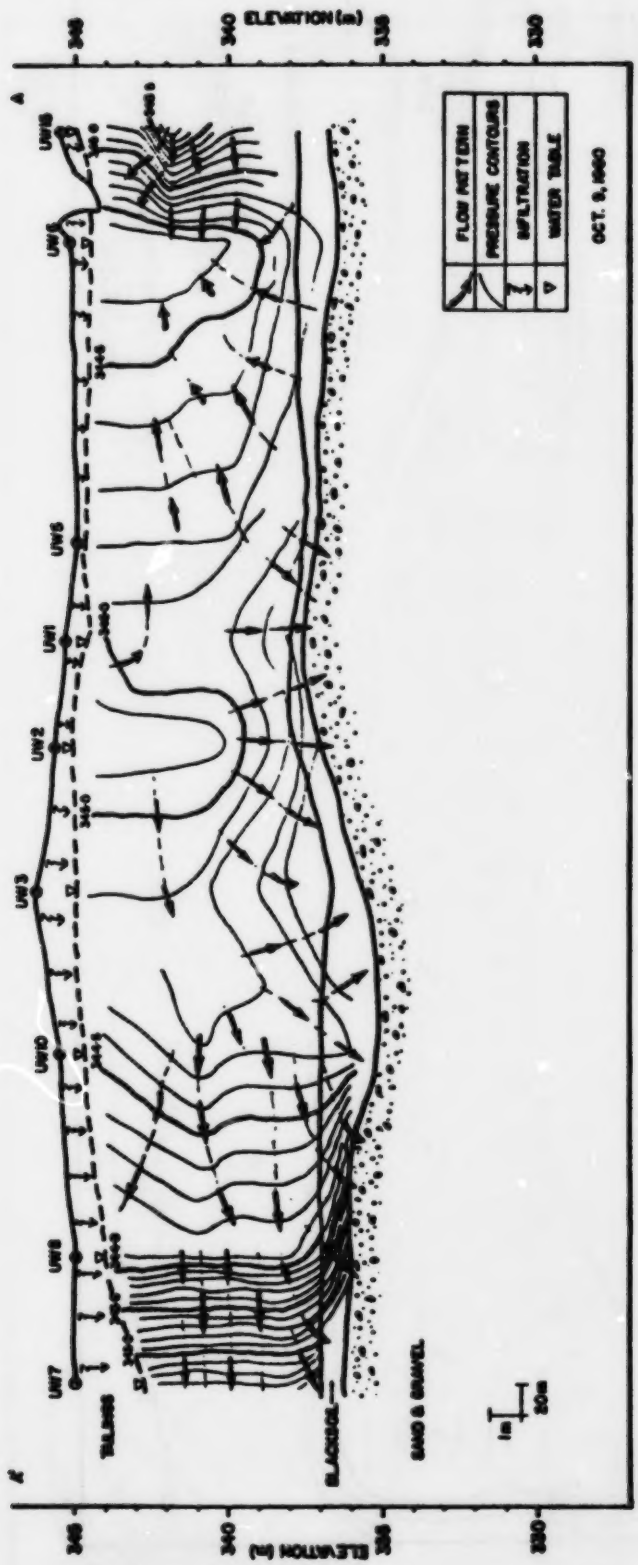

Fig. 8 - Vertical east-west cross-section A'-A, pressure contours and flow pattern in the Nordic West Arm tailings, Fall 1980.

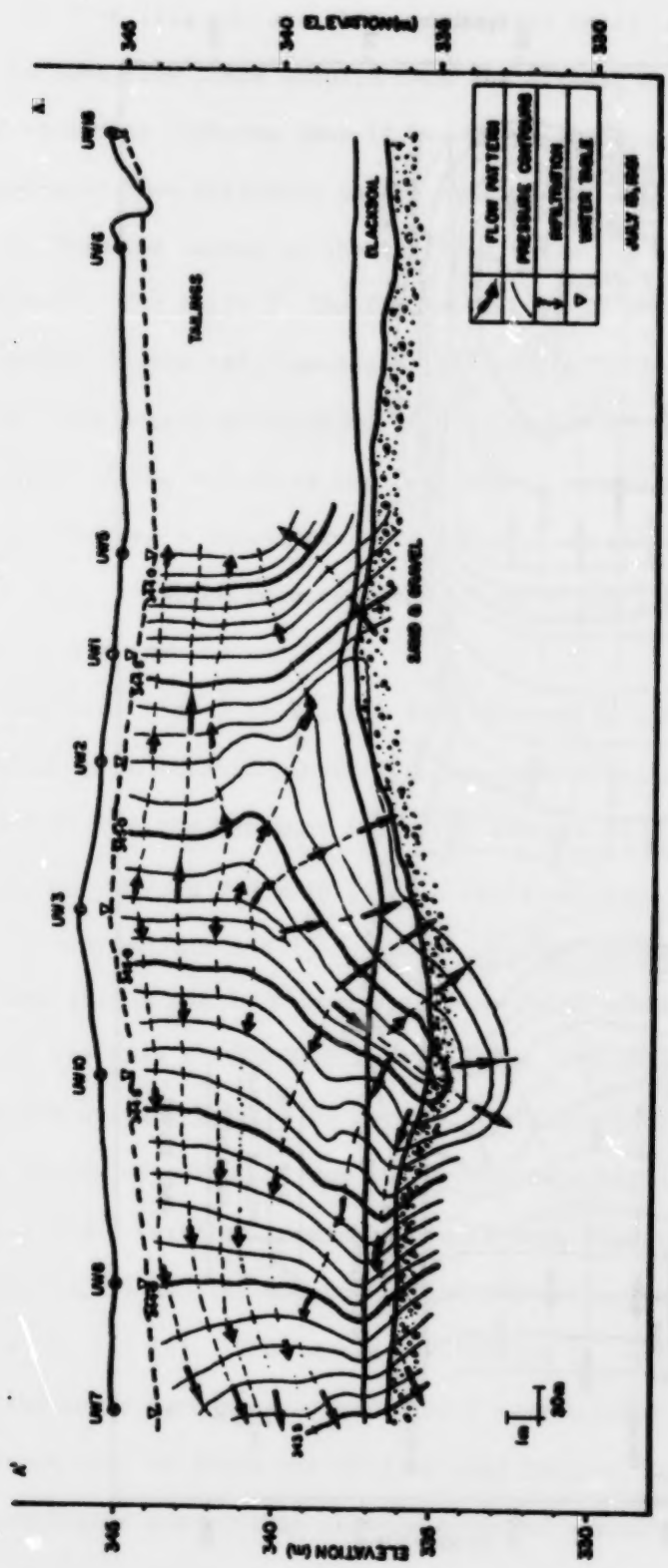

Fig. 9 - Vertical east-west cross-section A'-A, pressure contours and flow pattern in the Nordic West Arm tailings, Summer 1981.

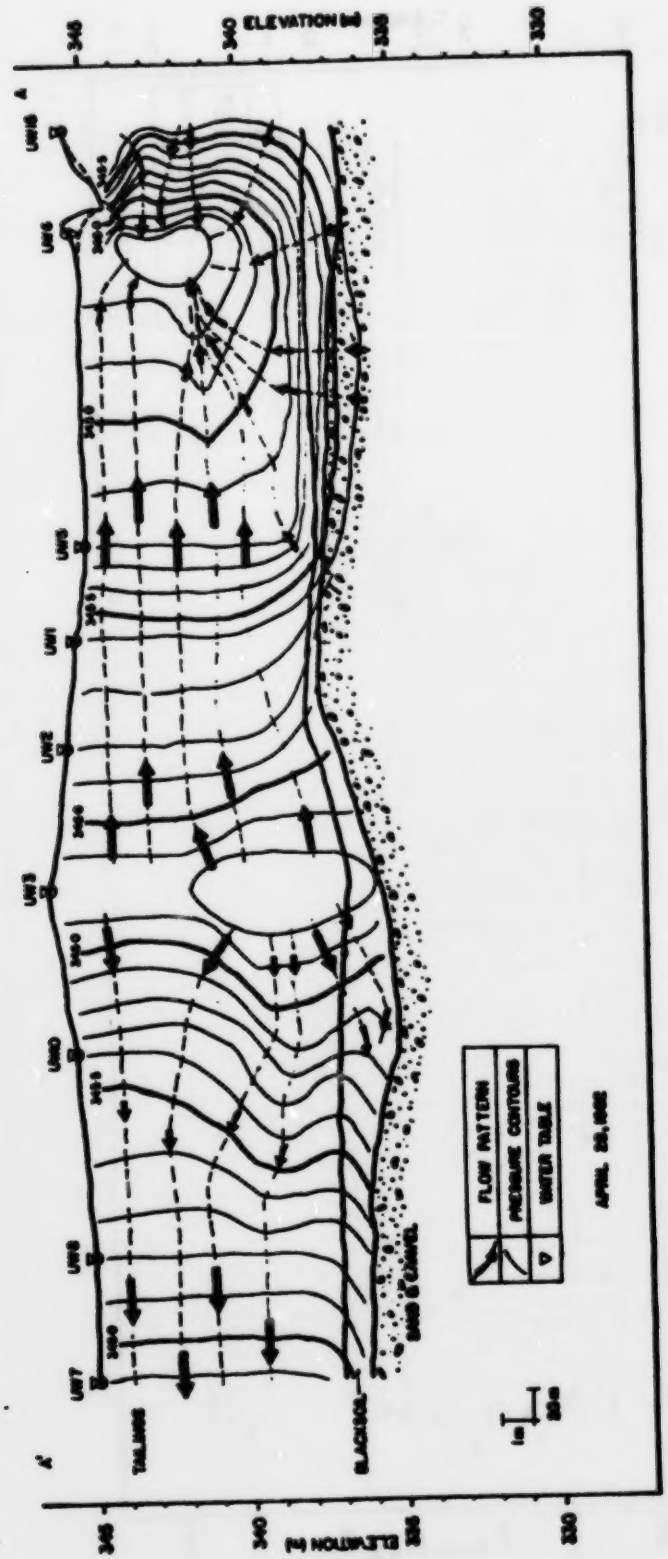

Fig. 10 - Vertical east-west cross-section A'-A, pressure contours and flow pattern in the Nordic West Arm tailings, Spring 1982.

D'-D, E'-E, and F'-F (Fig. 2) are shown in Fig. 11 to 25.

It is seen from these results that the highest water table was recorded during spring recharge when it was at the tailings surface. The general groundwater flow direction in the tailings is divided eastward and westward, away from the centre of the tailings where the highest pressurehead mound is situated. The split in the flow direction is probably caused by the surface topography of the tailings and by the inflow from the surrounding steep bedrock hills. The pressurehead mound also shifted with the season, moving from west to east of the divide as the fall season approached (Fig. 5 to 7). During spring recharge, a strong pressure gradient in the northern direction was also observed (Fig. 7) which resulted from snowmelt and runoff from the southern hill of the impoundment.

As seen from Fig. 5 to 10, the flow pattern in the eastern half is complex, varying in an erratic manner with seasonal changes. The overall horizontal flow within the tailings is in the eastern direction with gradients ranging from 2.5×10^{-3} to 7.3×10^{-3}. The vertical component of the gradient in this area is not uniform and is caused by erratic changes in the flow pattern. A very strong and localized westerly upward gradient was observed at location #6, at the base of the main tailings dam 'C', which decreased towards the middle of the eastern half. The strong upward gradient in this area was caused by the inflow of effluent from the Nordic Main tailings situated above the Nordic West Arm. Vertical upward gradients were observed across the peat layer (Fig. 12, 13, 15 and 16) except in fall 1980 when the gradients were downwards (Fig. 11 and 14). The latter observation is uncharacteristic of the eastern half and could have been affected by a test conducted all summer in 1980 by Rio Algom Ltd. to drain the holding pond between dam 'A' and 'B' (Fig. 1). Groundwater and visible seepage occurred across dam 'D' (Fig. 1) to

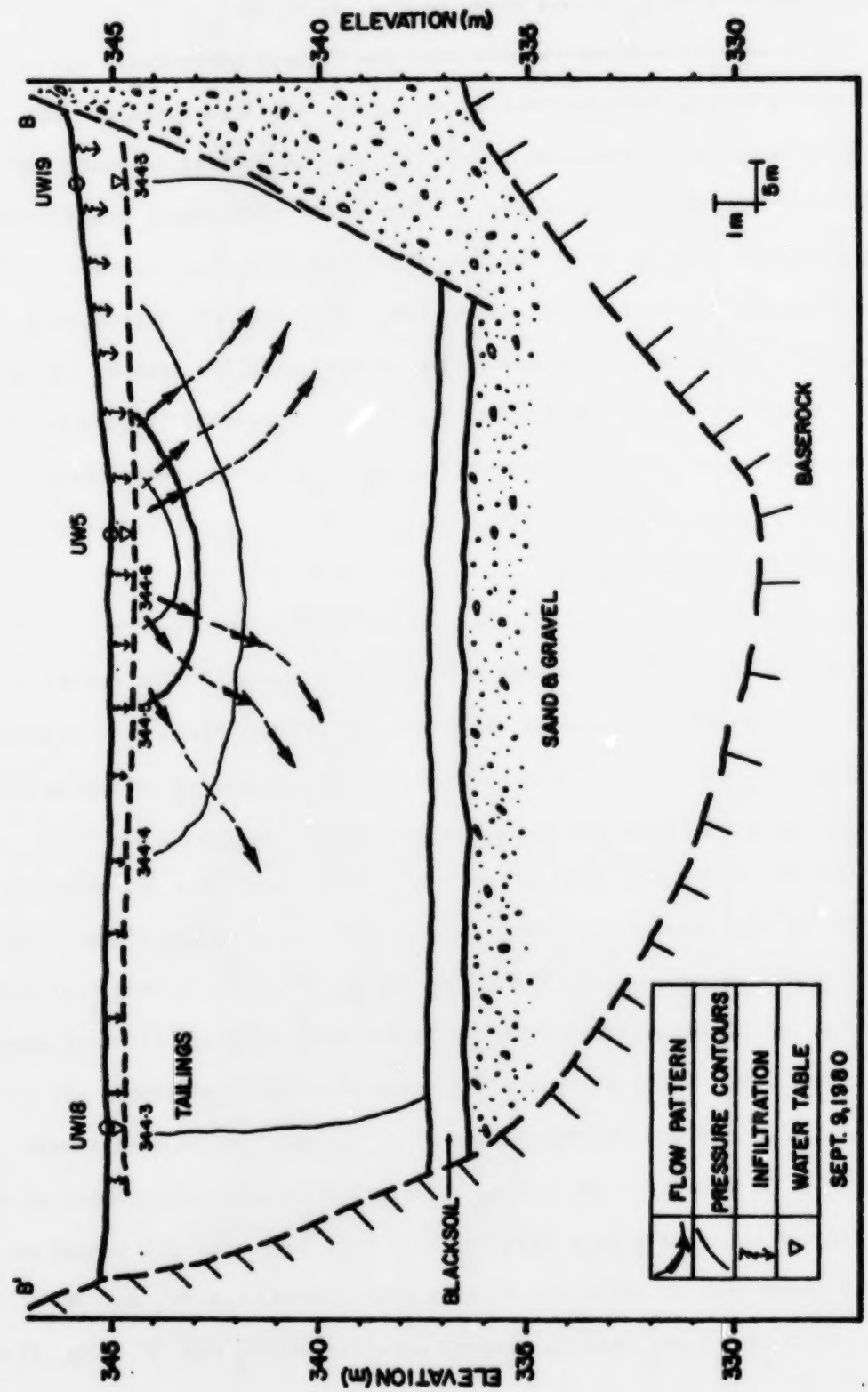

Fig. 11 - Vertical north-south cross-section B'-B, pressure contours and flow pattern in the Nordic West Arm tailings, Fall 1980.

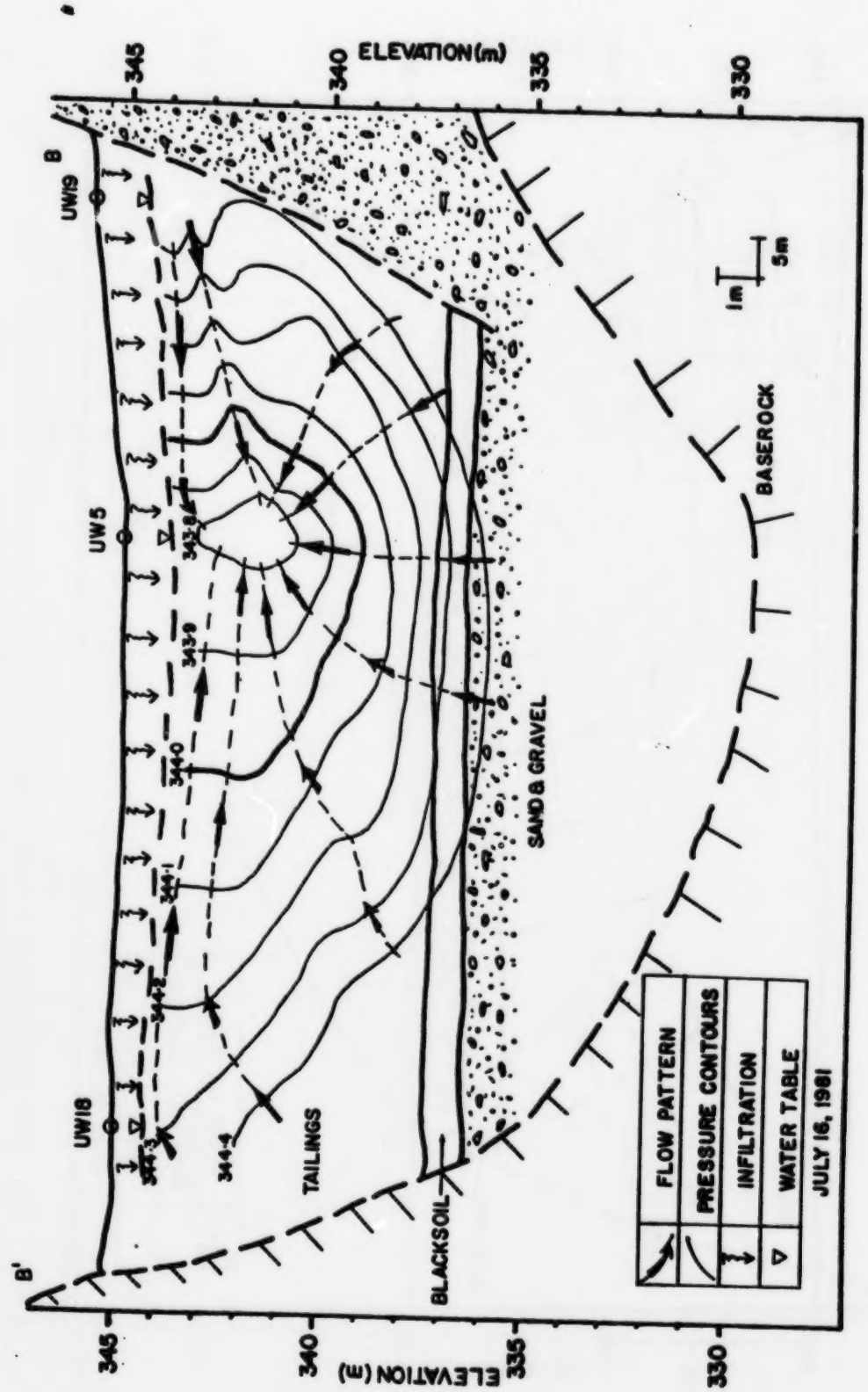

Fig. 12 - Vertical north-south cross-section B'-B, pressure contours and flow pattern in the Nordic West Arm tailings, Summer 1981.

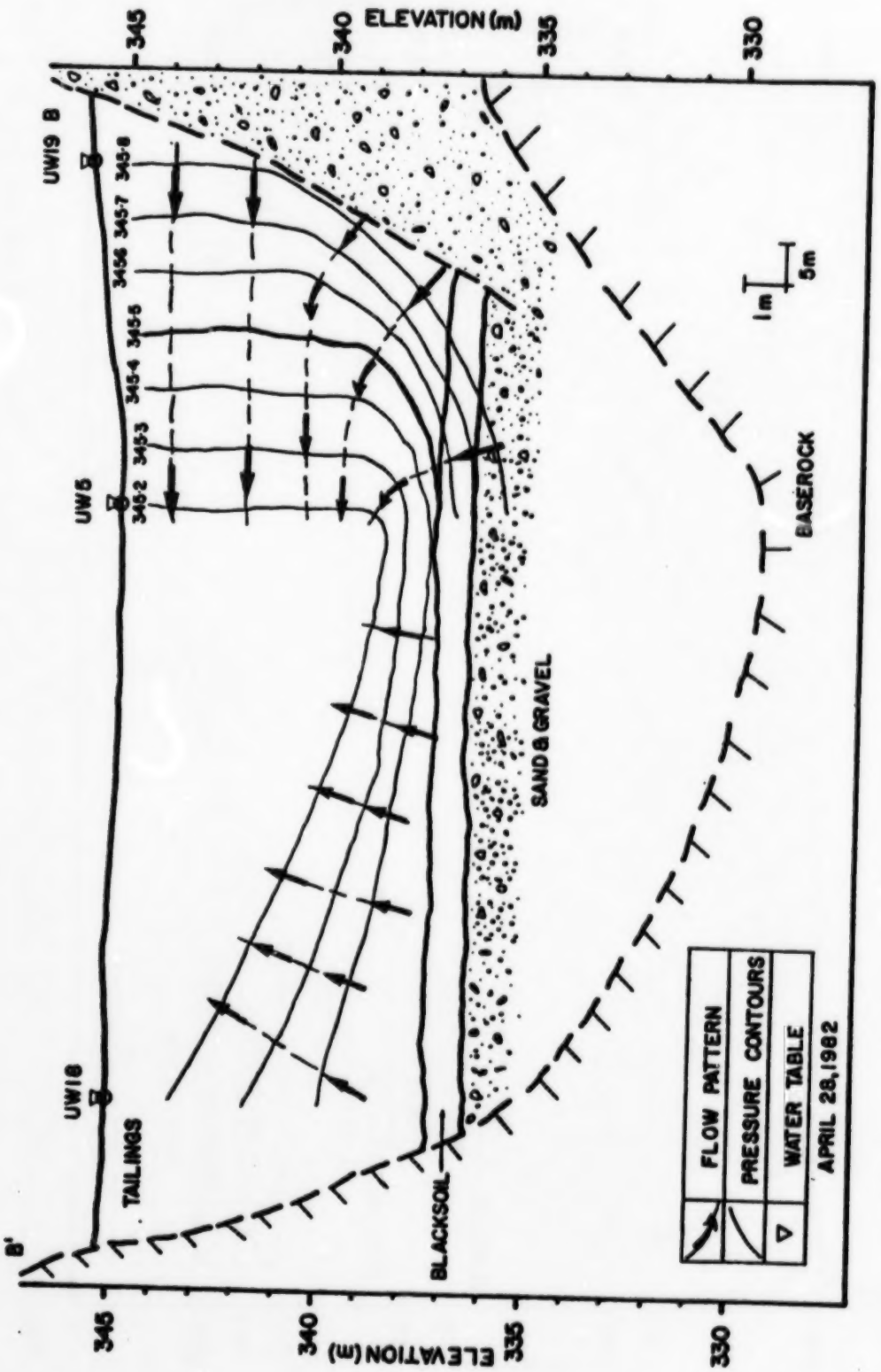

Fig. 13 - Vertical north-south cross-section B'-B, pressure contours and flow pattern in the Nordic West Arm tailings, Spring 1982.

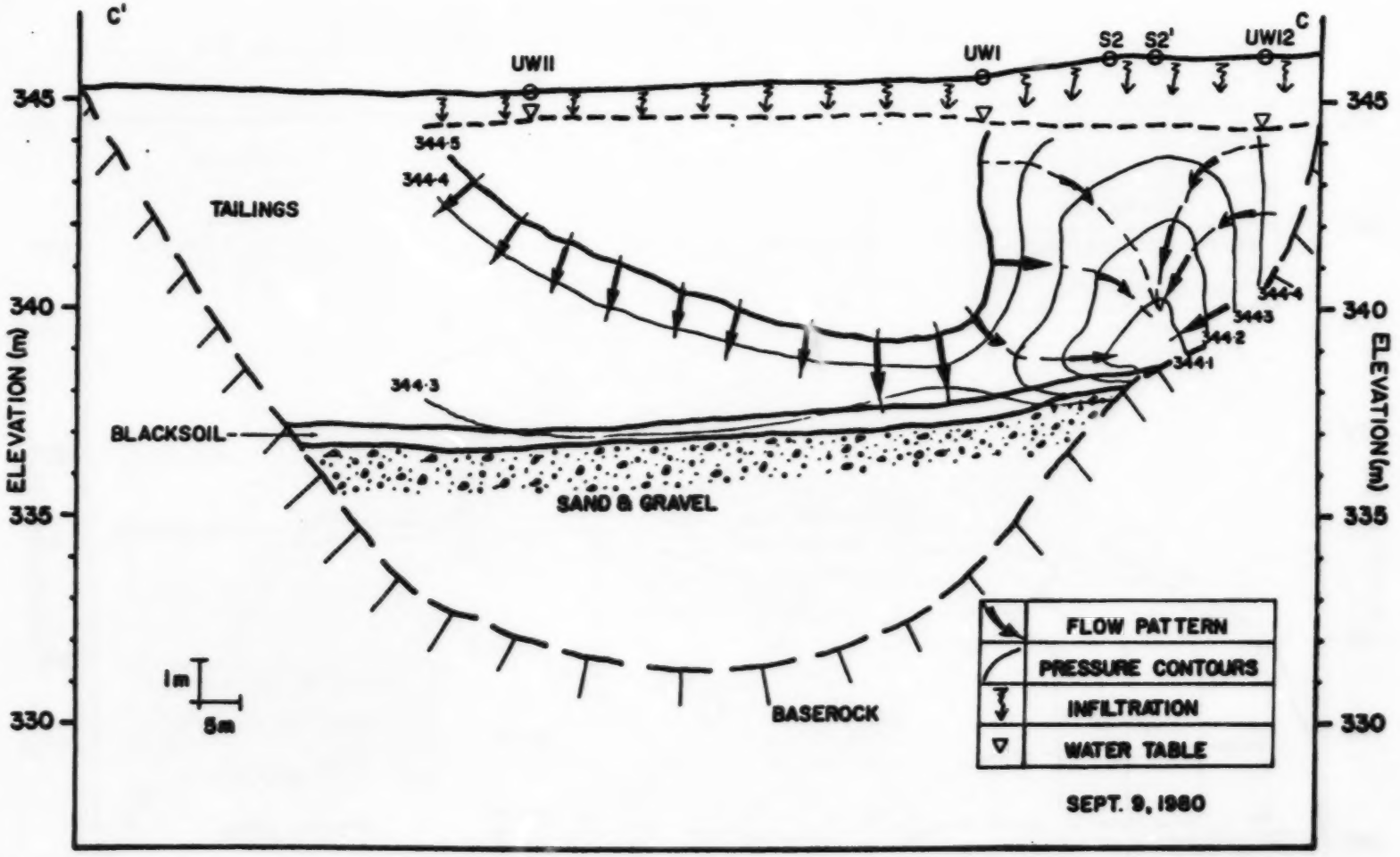

Fig. 14 - Vertical north-south cross-section C'-C, pressure contours and flow pattern in the Nordic West Arm tailings, Fall 1980.

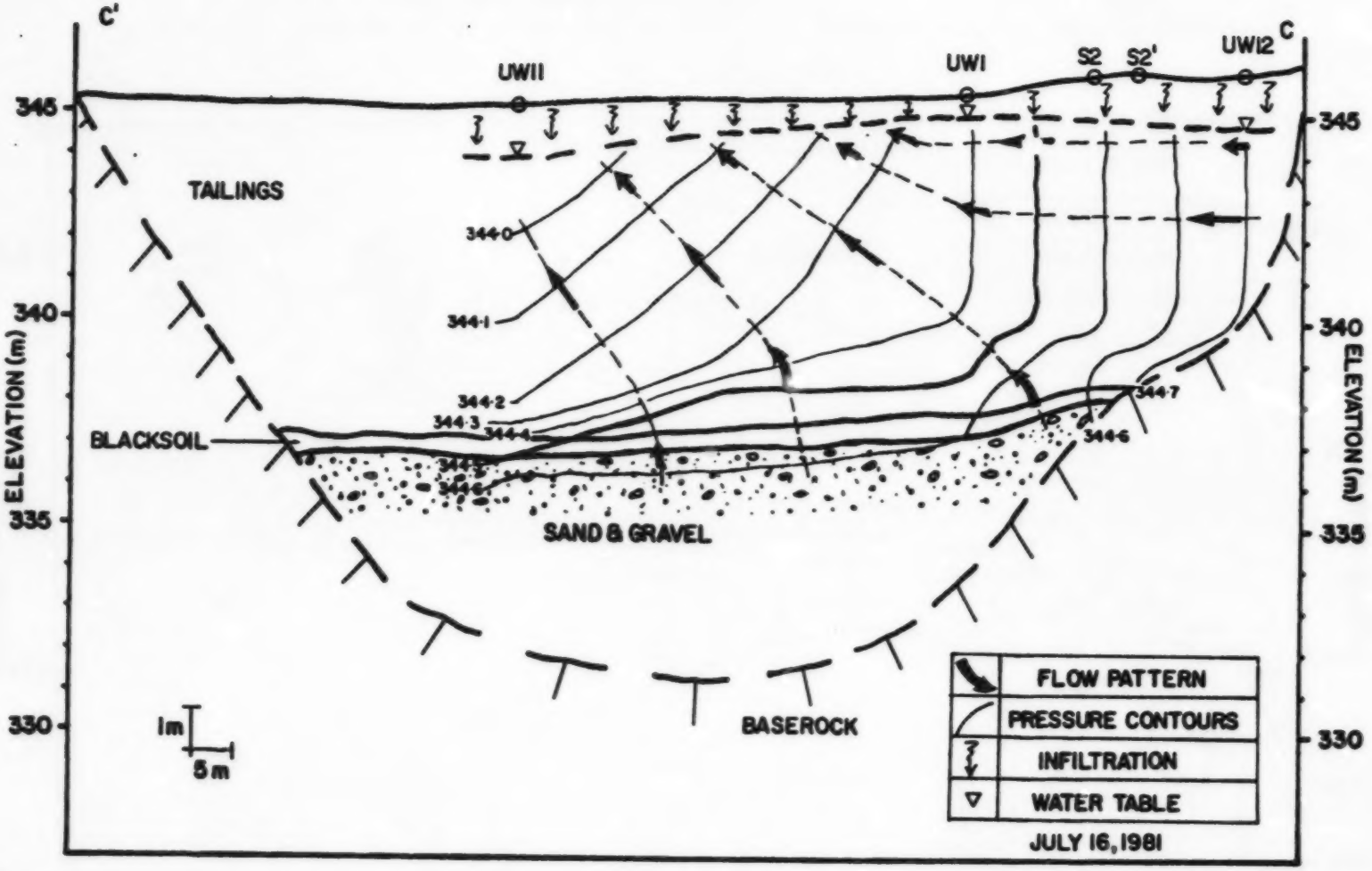

Fig. 15 - Vertical north-south cross-section C'-C, pressure contours and flow pattern in the Nordic West Arm tailings, Summer 1981.

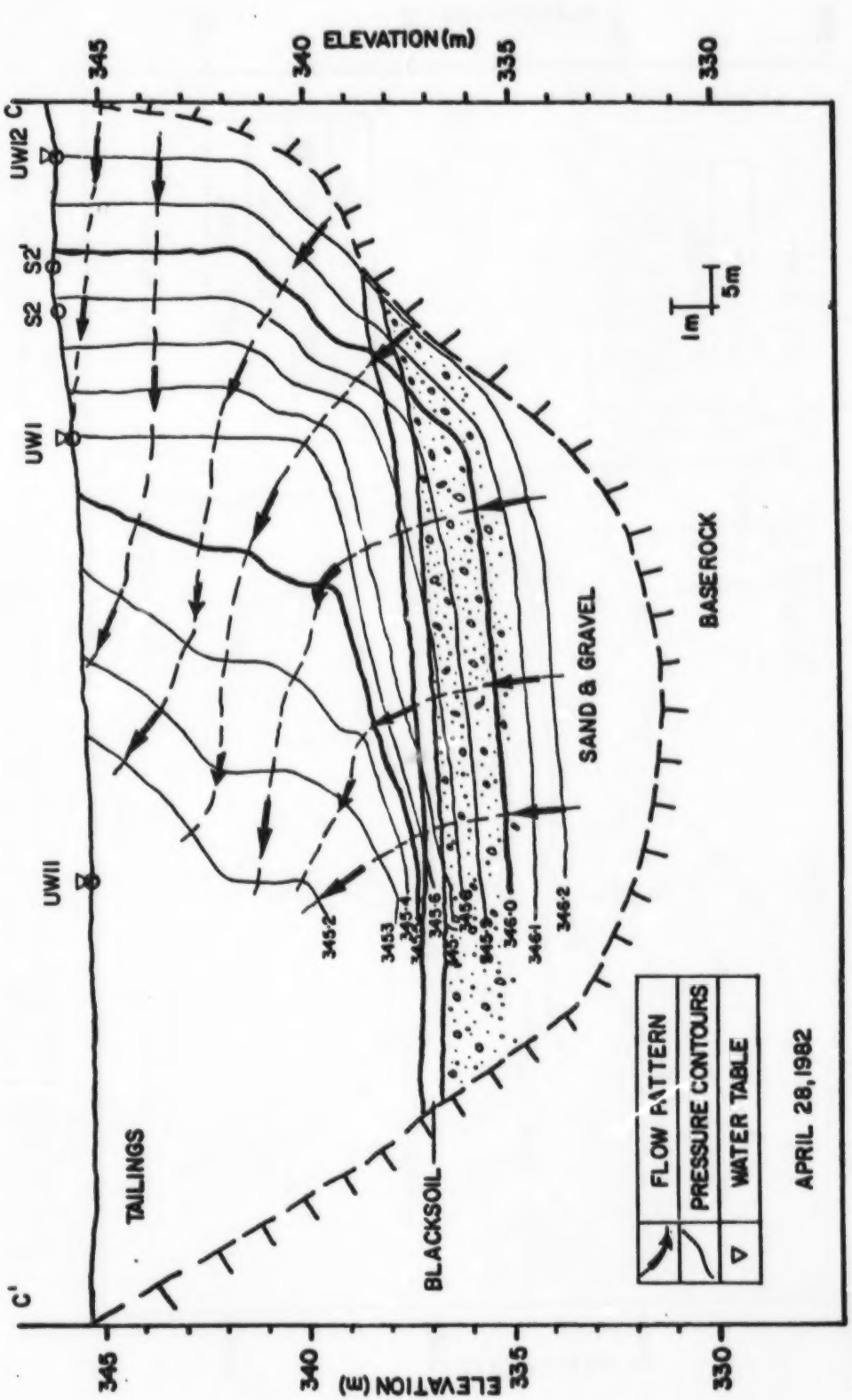

Fig. 16 - Vertical north-south cross-section C'-C, pressure contours and flow pattern in the Nordic West Arm tailings, Spring 1982.

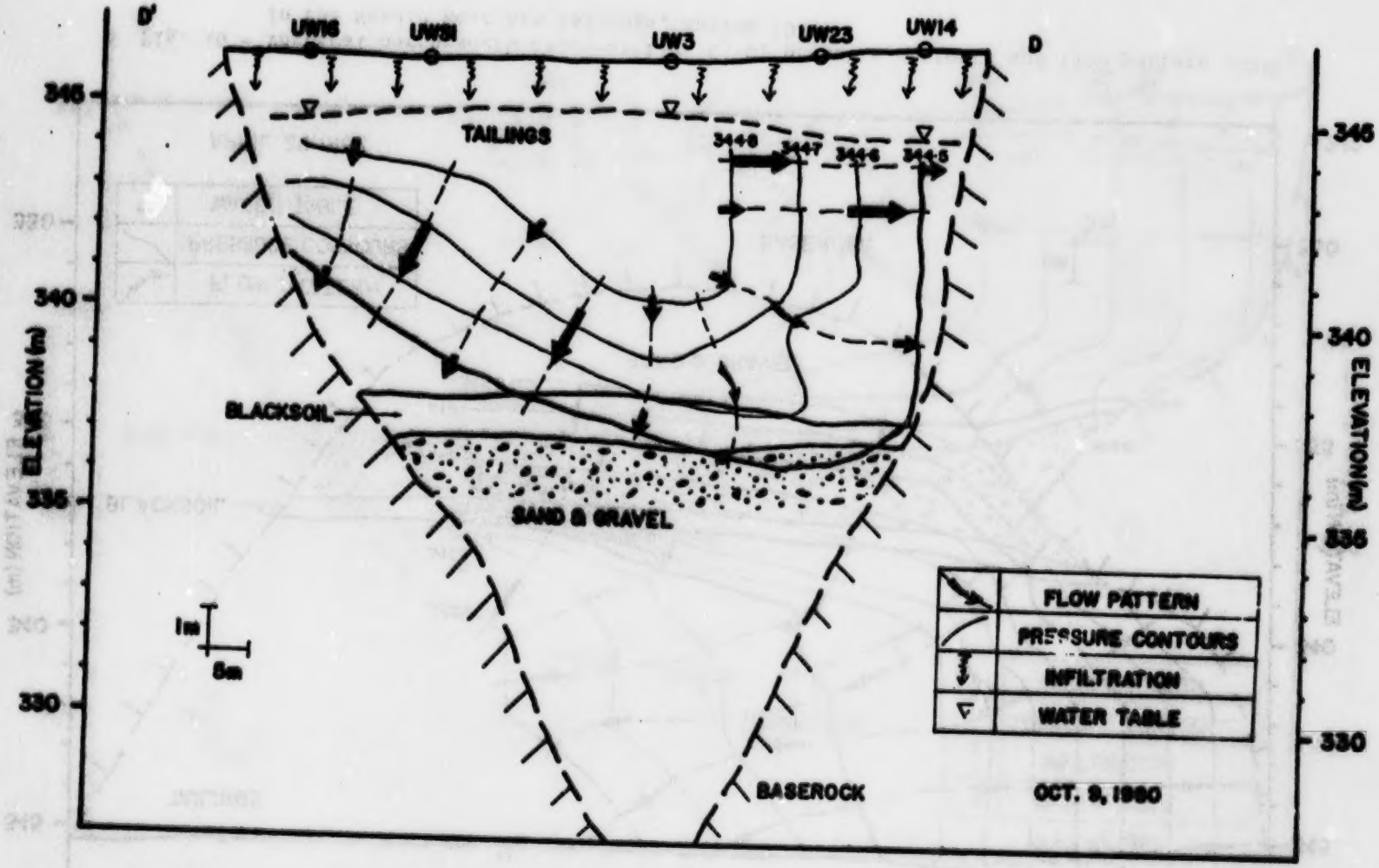

Fig. 17 - Vertical north-south cross-section D'-D, pressure contours and flow pattern in the Nordic West Arm tailings, Fall 1980.

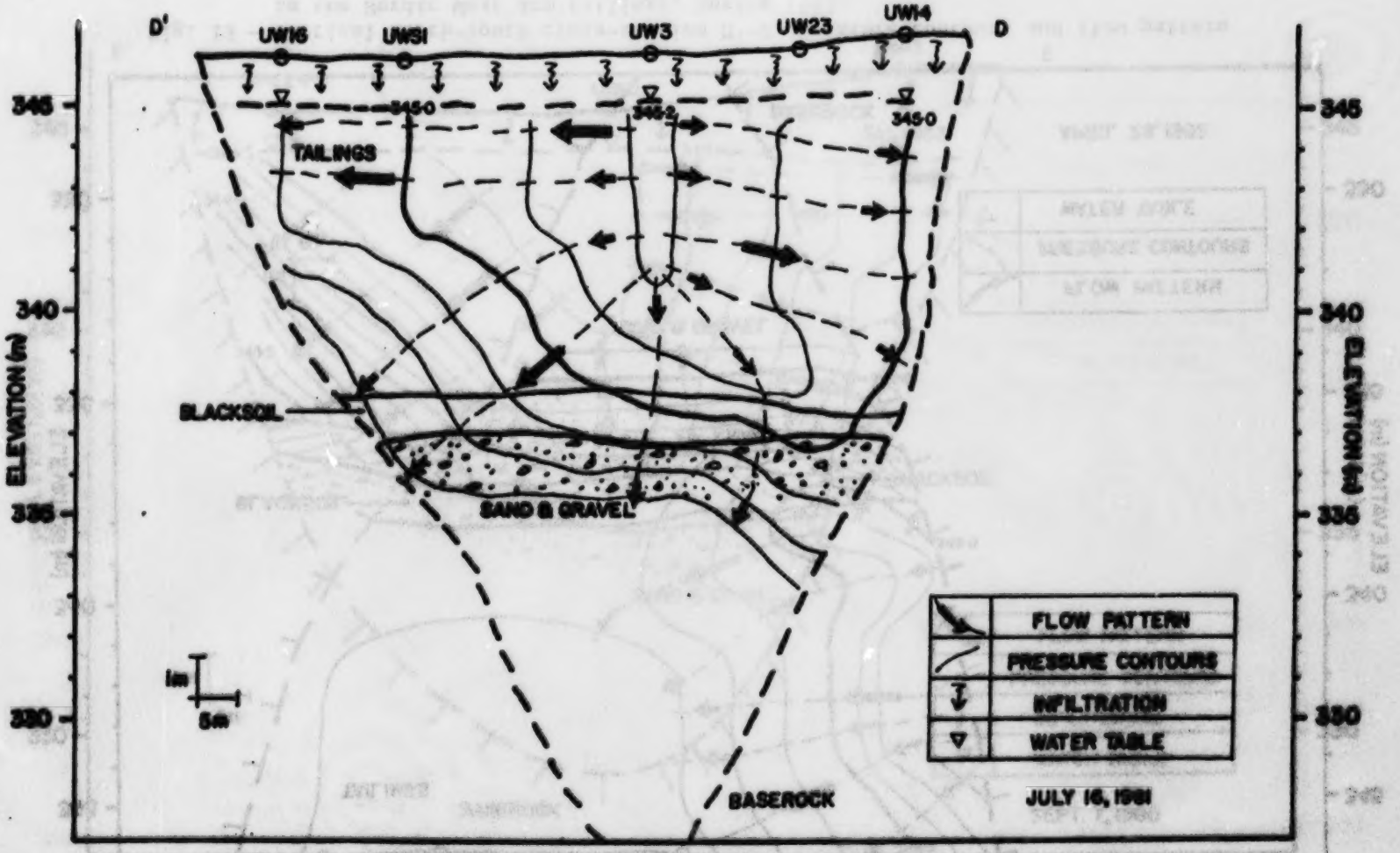

Fig. 18 - Vertical north-south cross-section D'-D, pressure contours and flow pattern in the Nordic West Arm tailings, Summer 1981.

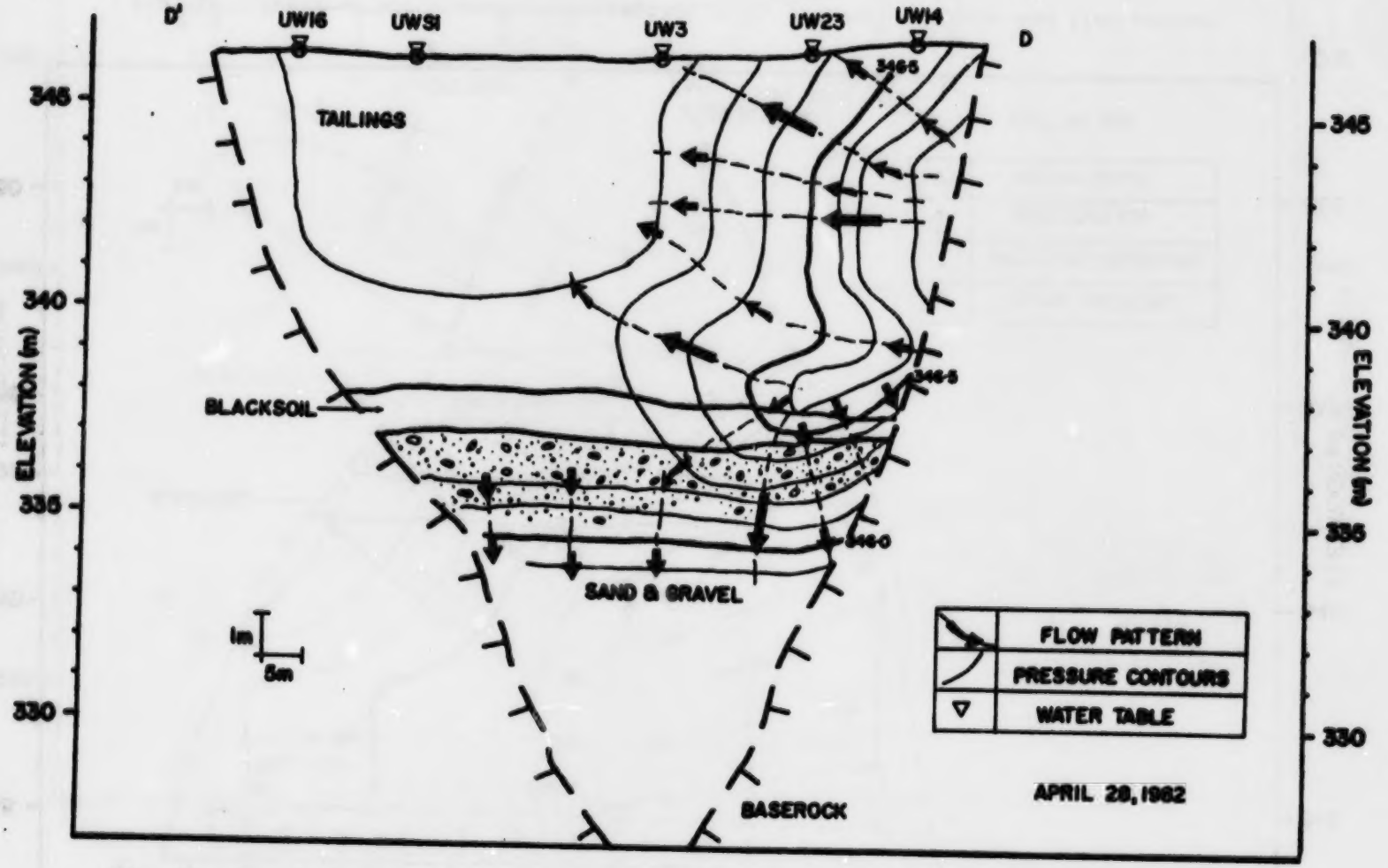

Fig. 19 - Vertical north-south cross-section D'-D, pressure contours and flow pattern in the Nordic West Arm tailings, Spring 1982.

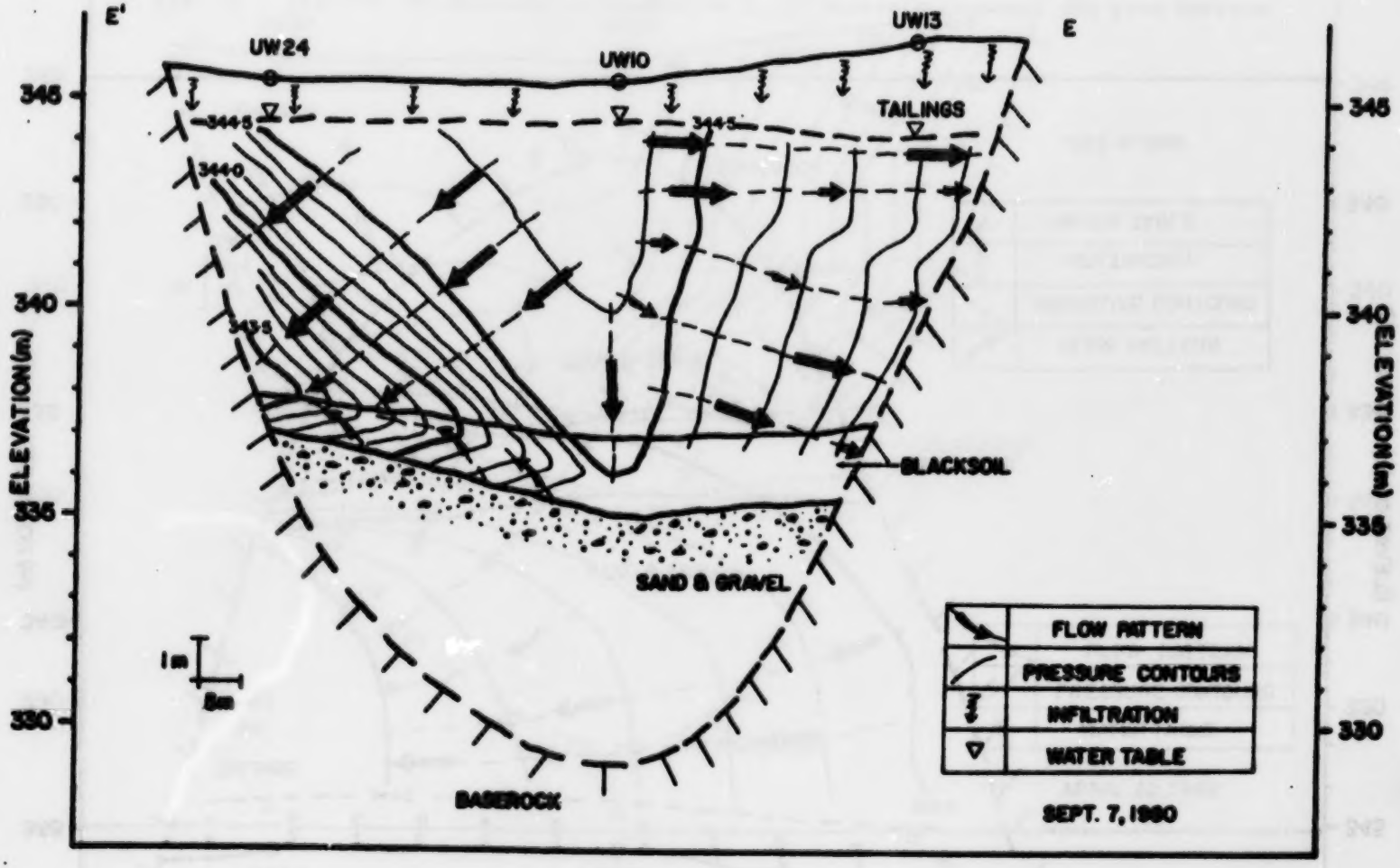

Fig. 20 - Vertical north-south cross-section E'-E, pressure contours and flow pattern in the Nordic West Arm tailings, Fall 1980.

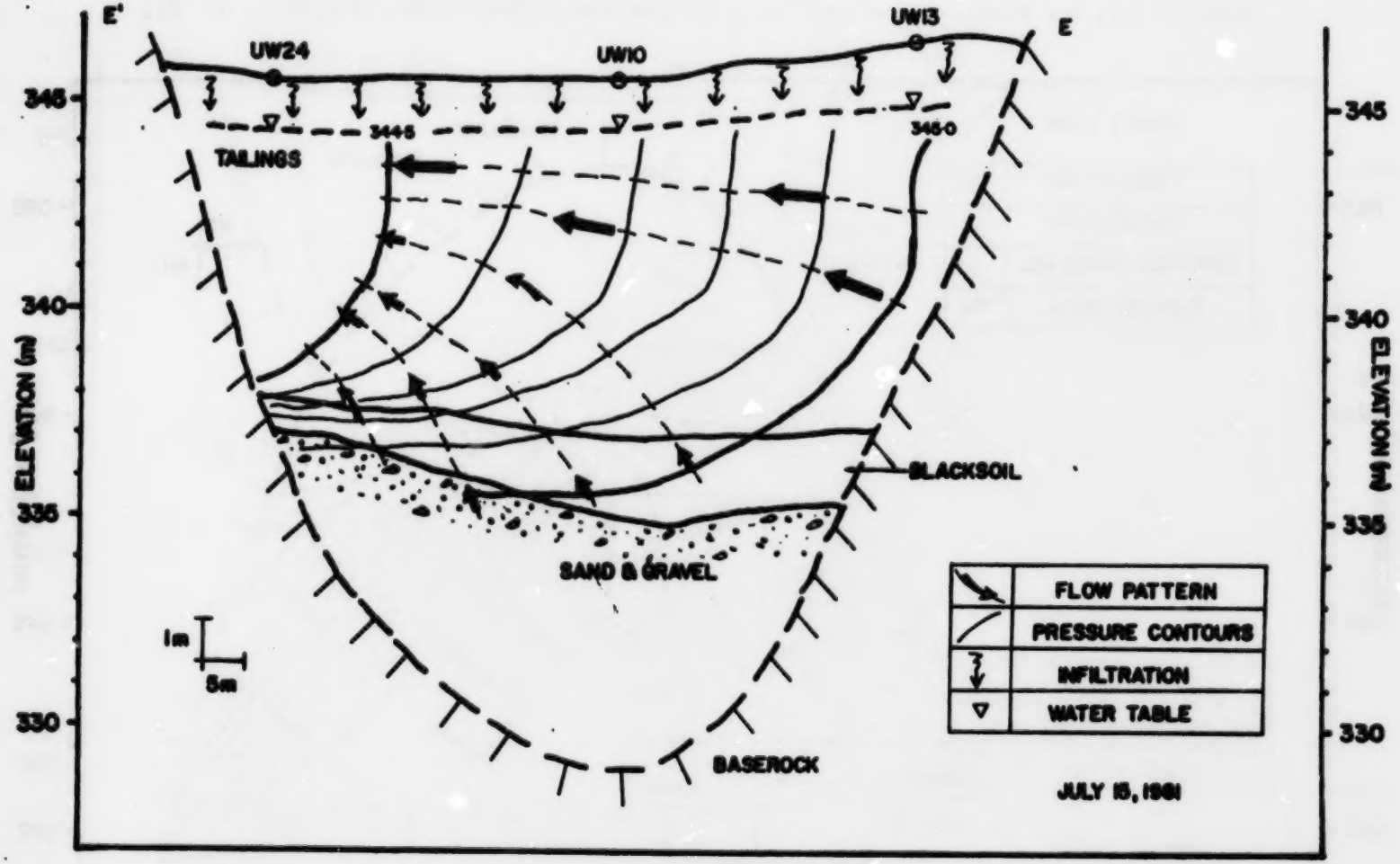

Fig. 21 - Vertical north-south cross-section E'-E, pressure contours and flow pattern in the Nordic West Arm tailings, Summer 1981.

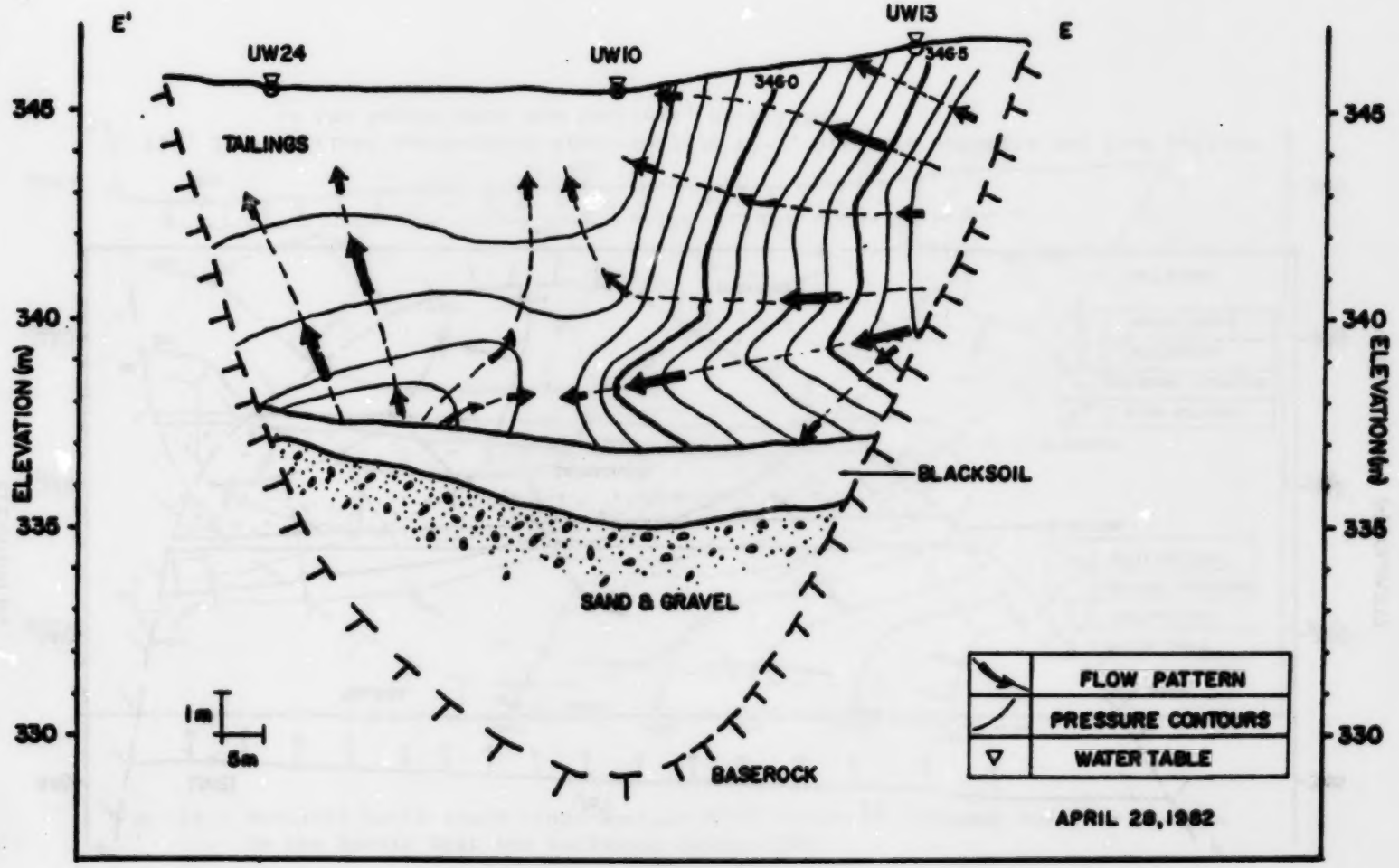

Fig. 22 - Vertical north-south cross-section E'-E, pressure contours and flow pattern in the Nordic West Arm tailings, Spring 1982.

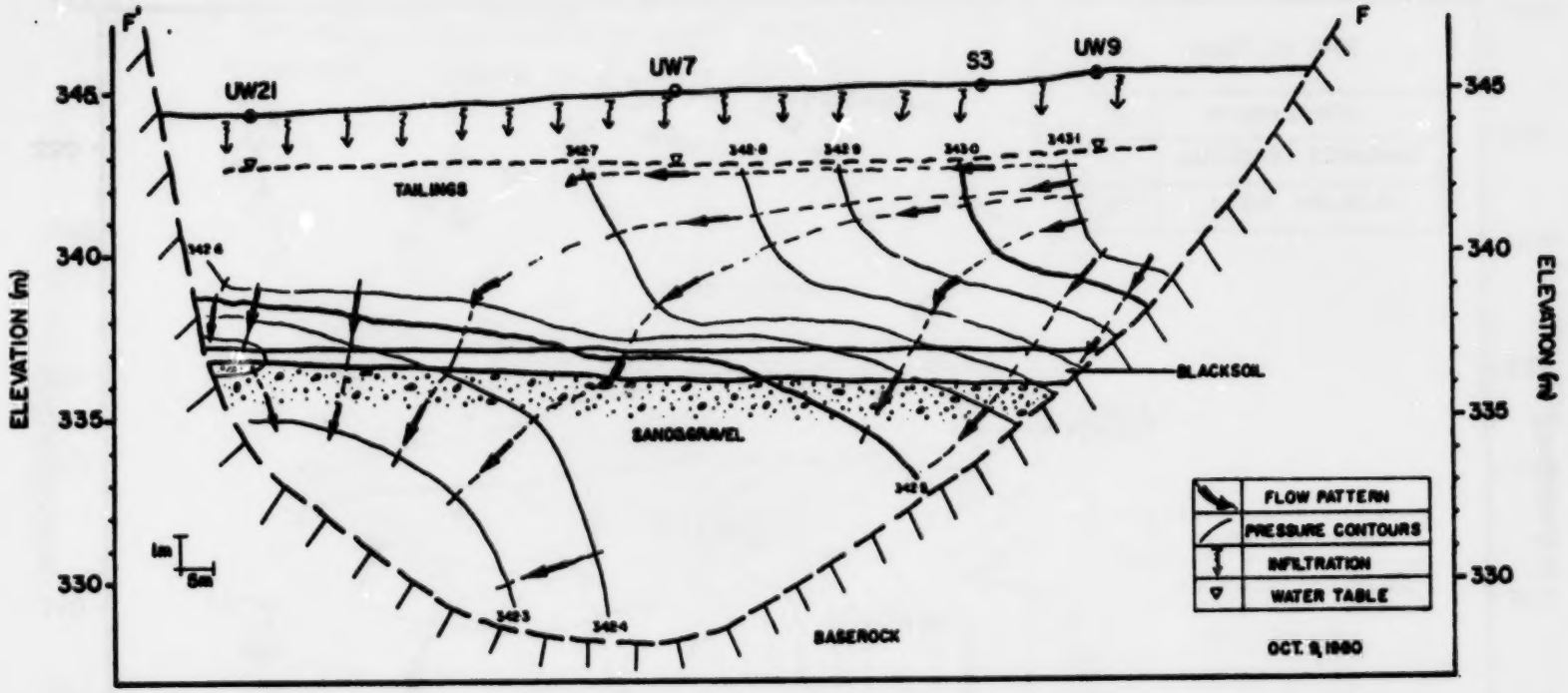

Fig. 23 - Vertical north-south cross-section F'-F, pressure contours and flow pattern in the Nordic West Arm tailings, Fall 1980.

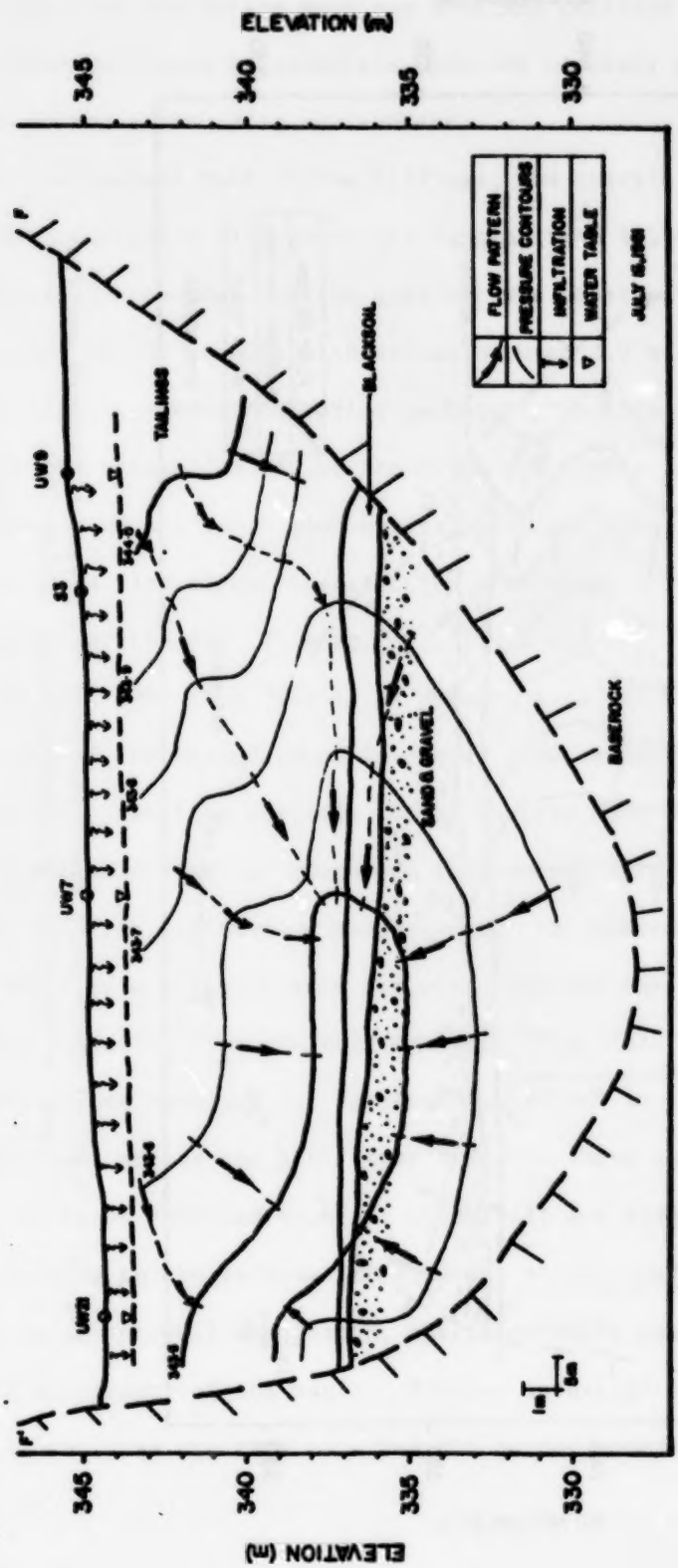

Fig. 24 - Vertical north-south cross-section F'-F, pressure contours and flow pattern in the Nordic West Arm tailings, Summer 1981.

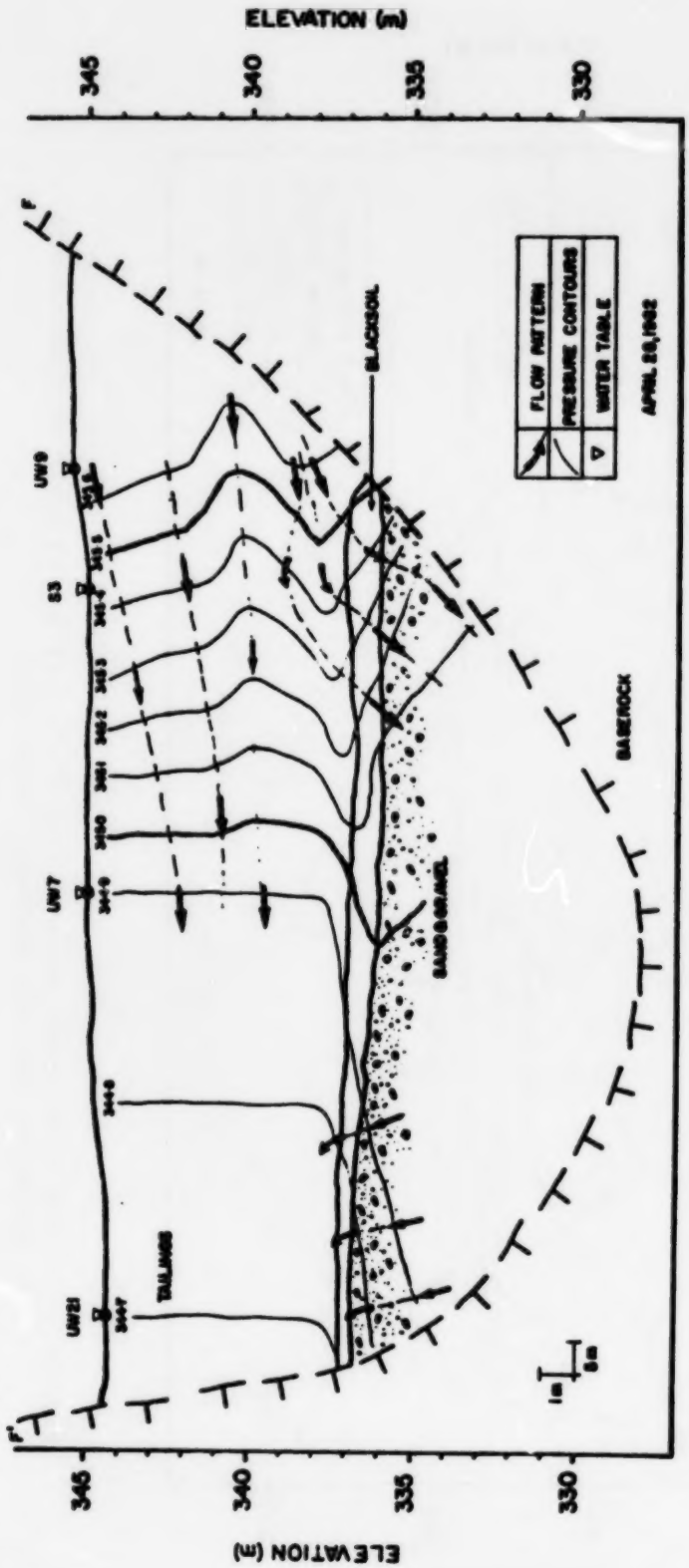

Fig. 25 - Vertical north-south cross-section F'-F, pressure contours and flow pattern in the Nordic West Arm tailings, Spring 1982.

the south both from the Nordic Main and West Arm tailings areas. In this area, it is therefore difficult to calculate with any accuracy the groundwater flux discharging to the surrounding environment.

In the western half of the tailings, the overall horizontal flow was in the western direction with gradients ranging from 4.1×10^{-3} to 5.3×10^{-3}. A strong northerly component of the gradient was observed towards the dam "B" (Fig. 6, 7, 18, 19, 21 and 22) with values between 3.9×10^{-3} to 6.9×10^{-3} and was the highest during the spring recharge. In this area, the major seepage front is located across dam 'B' at the north end with a smaller front located at the south end of the dam. The vertical gradient across the peat layer showed a downward flow along cross-section D'-D (Fig. 17-19) which gradually turned upward near the dam 'B' (Fig. 20, 21, 22 and 24). The observed downward flow in fall 1980 (Fig. 23) is an exception to the trend and was caused by the pumping of the holding pond in summer 1980 as mentioned before. Unlike the eastern half, the flow patterns in the western half are relatively simple making it a suitable site for computing groundwater flux entering from the tailings area to the surrounding environment. The general topography of the area also makes it a suitable site for environmental impact modelling of contaminants migrating from the tailings area (Fig. 26).

The values obtained for horizontal gradient in the tailings pile and vertical gradient across the peat layer from the three seasonal data are comparable to those obtained by Blair et al. (1) and Blackport (3). The mechanism leading to the reversal of gradient across the peat layer in the tailings area is not well understood, but is probably caused by the bedrock (base rock) topography of the basin. Further investigations of the bedrock profiling in the area are thus required for better understanding of the situation.

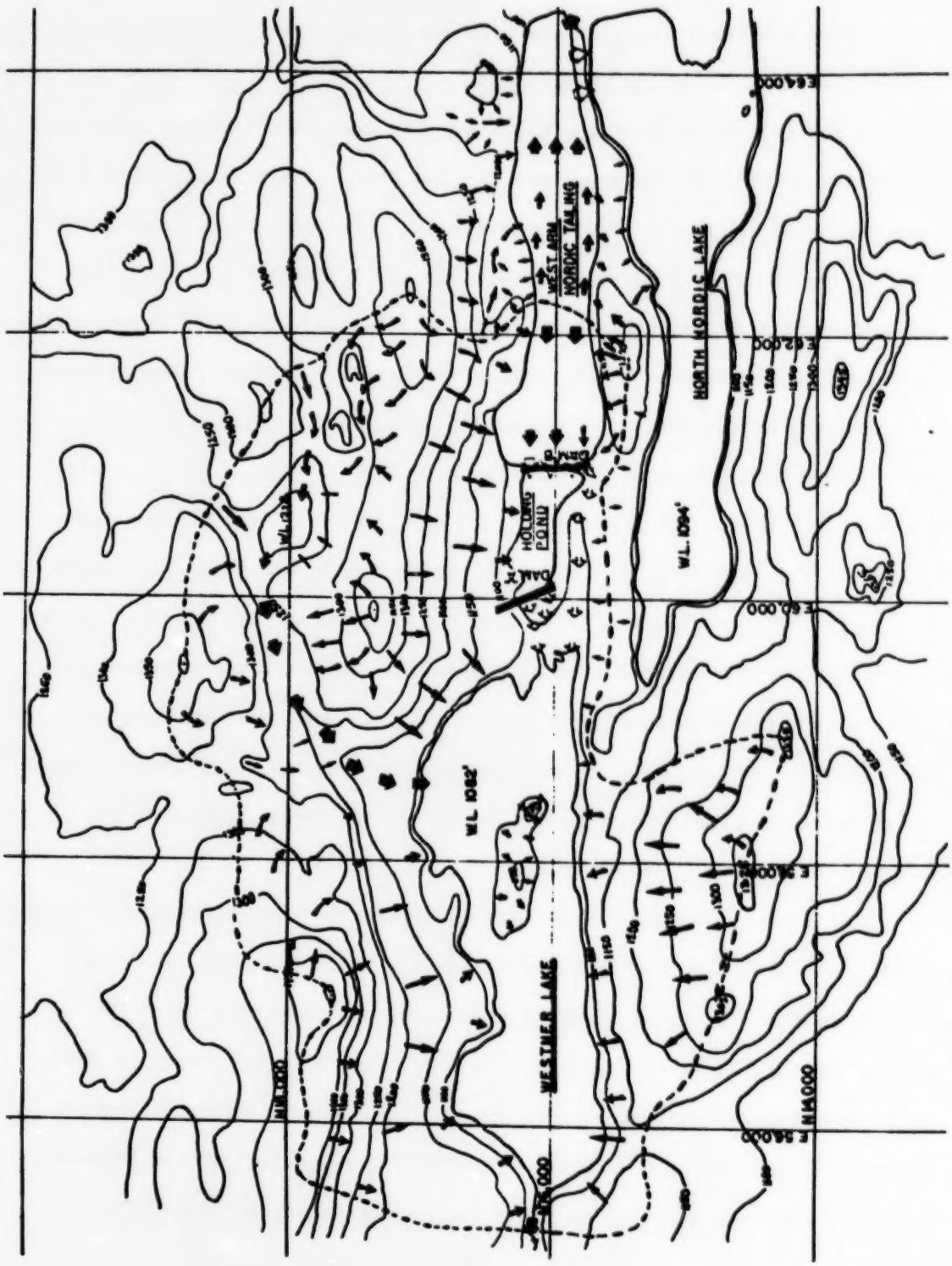

Fig. 26 - Westner Lake watershed system and the flow of effluent from the Nordic West Arm tailings area.

SUMMARY

In the Nordic West Arm tailings, the general groundwater flow was divided in east and west directions away from the mid-section where a high pressurehead mound existed.

The flow pattern in the eastern half of the tailings was unstable with non-uniform vertical gradients changing at times and locations from upward to downward flow. A strong inflow of seepage from the Nordic Main tailings significantly affected the quantity and probably the quality of the seepage outflow from this area. The seepage front along the dam 'D' is thus very indistinct, making the site undesirable for environmental pathway modelling.

The western half of the tailings area, on the other hand, showed a more stable flow pattern with uniform gradients. The area represented a single source of contaminant, without other contaminant inflow that could significantly affect the source, except inflow of natural groundwater, spring recharge and runoff, which is the driving mechanism of the observed flow pattern. All the seepage from this area flowed towards Westner Lake and with the known cross-section area, pressure gradient and hydraulic conductivity, the total seepage discharge from this area to the surrounding environment could be calculated with a reasonable accuracy. This makes it a suitable study site for tailings area environmental pathway modelling.

ACKNOWLEDGEMENT

The authors wish to thank Mr. M. Turcotte, Miss Y. Sleypen and Mr. G. Chodola of the Surface Environmental Technology Group, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario, and Mr. K. Bisson and Mr. L. Lance of the Surface Environmental Engineering Department, Rio Algom Ltd., Elliot Lake, Ontario, for their assistance in conducting the field study.

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